Hubble Space Telescope

Cycle 12 GO Proposal

Spectroscopic Binaries in the R 136 Cluster: Measuring the Masses of the Highest Mass Stars Known

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Scientific Category: HOT STARS

Scientific Keywords: MASSIVE STARS

Instruments: STIS

Proprietary Period: 12

Cycle 12 primary orbits: 45

Abstract

Empirical checks on the mass-luminosity relationship for massive stars are sorely needed, as there are significant differences between the masses derived from stellar evolutionary and stellar atmosphere models. Yet we rely upon these models for our knowledge of the initial mass function and turn-off masses in clusters, for understanding star-formation of high mass stars, and for providing evolutionary links between O-type stars and Wolf-Rayets, Red Supergiants, and Lumnous Blue Variables. Masses derived from atmospheric models have usually yielded results as much as a factor of two lower than that derived from the stellar evolutionary models. Observational checks are possible by directly measuring the masses in detached, eclipsing binary systems, but only a handful of such systems are known for high mass stars. In Cycle 8 we obtained spectroscopy and photometry of 4 very massive binaries in the R136 "super star cluster", finding the highest mass star yet known (Massey et al 2002, ApJ, 565, 982). For the three systems that proved to be eclipsing, we found excellent agreement with the masses determined from stellar evolutionary code. In the course of that study we identified five other eclipsing systems for which spectroscopy would yield masses, and it is for this followup work that we are proposing here. Hopefully one or more of these new systems will have periods sufficiently long to remove the spectre of tidal interactions having affected their locations in the H-R diagram, a problem that we did encounter in our earlier study. We can also use this time to also obtain higher S/N spectra on the highest mass binary we previously discovered, in order to do a photospheric line analysis allowing an "atmospheric model" mass to be determined, providing an unprecedented test of whether the new and improved atmosphere models now agree with reality. We can accomplish all of this using only 15 visits (3 orbits each) by taking advantage of HST's excelent offsetting capabilities and by carefully spacing the observations.

Investigators:

	Investigator	Institution	Country
PI	Dr. Philip Massey	Lowell Observatory	USA/AZ
CoI	Dr. Laura Penny	College of Charleston	USA/SC
CoI*	Dr. Artemio Herrero	Instituto de Astrofisica de Canarias	Spain

Number of investigators: 3

* ESA investigators: 1

Observing Summary:

Target	RA	DEC	V	Config/Mode/SEs	Flags	Orbits
R136	05 39 0.00	-69 06 0.00	9.5	STIS/CCD/Imaging/F28X50LP	DUP	0
R136	05 39 0.00	-69 06 0.00	9.5	STIS/CCD/Spectroscopic/G430M	DUP	3
R136	05 39 0.00	-69 06 0.00	9.5	STIS/CCD/Imaging/F28X50LP	DUP	0
R136	05 39 0.00	-69 06 0.00	9.5	STIS/CCD/Spectroscopic/G430M	DUP	3
R136	05 39 0.00	-69 06 0.00	9.5	STIS/CCD/Imaging/F28X50LP	DUP	0
R136	05 39 0.00	-69 06 0.00	9.5	STIS/CCD/Spectroscopic/G430M	DUP	3
R136	05 39 0.00	-69 06 0.00	9.5	STIS/CCD/Imaging/F28X50LP	DUP	0
R136	05 39 0.00	-69 06 0.00	9.5	STIS/CCD/Spectroscopic/G430M	DUP	3
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R136	05 39 0.00	-69 06 0.00	9.5	STIS/CCD/Imaging/F28X50LP	DUP	0
R136	05 39 0.00	-69 06 0.00	9.5	STIS/CCD/Spectroscopic/G430M	DUP	3
R136	05 39 0.00	-69 06 0.00	9.5	STIS/CCD/Imaging/F28X50LP	DUP	0
R136	05 39 0.00	-69 06 0.00	9.5	STIS/CCD/Spectroscopic/G430M	DUP	3
R136	05 39 0.00	-69 06 0.00	9.5	STIS/CCD/Imaging/F28X50LP	DUP	0
R136	05 39 0.00	-69 06 0.00	9.5	STIS/CCD/Spectroscopic/G430M, G750M	DUP	3
R136	05 39 0.00	-69 06 0.00	9.5	STIS/CCD/Imaging/F28X50LP	DUP	0
R136	05 39 0.00	-69 06 0.00	9.5	STIS/CCD/Spectroscopic/G430M, G750M	DUP	3
R136	05 39 0.00	-69 06 0.00	9.5	STIS/CCD/Imaging/F28X50LP	DUP	0
R136	05 39 0.00	-69 06 0.00	9.5	STIS/CCD/Spectroscopic/G430M, G750M	DUP	3
R136	05 39 0.00	-69 06 0.00	9.5	STIS/CCD/Imaging/F28X50LP	DUP	0
R136	05 39 0.00	-69 06 0.00	9.5	STIS/CCD/Spectroscopic/G430M, G750M	DUP	3

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R136	05 39 0.00	-69 06 0.00	9.5	STIS/CCD/Spectroscopic/G430M, G750M	DUP	3
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				Total orbit request:		45

Scientific Justification

1 The Need for Direct Determinations of High-Mass Stellar Masses

Arguably the mass of a star is its most important property. Although the chemical composition and angular momentum can play significant secondary roles in determining the evolution of a star (particularly of a massive star), it is the star's mass which determines the rate at which nuclear reactions occur in the core, and thus determines the course of its life's journey through the H-R diagram.

Empirical checks on the mass-luminosity relation, and how well the evolutionary models match reality, are sorely lacking for high mass ($> 20\mathcal{M}_{\odot}$) stars, even near the zero-age main sequence (ZAMS) (Burkholder, Massey, & Morrell 1998; Gies 2002). For the highest mass stars, we expect the mass-luminosity relationship to be much flatter than the $L \propto M^4$ law that characterizes solar-type stars: for high-mass stars the primary opacity source becomes scattering from free electrons, as higher interior temperatures result in more complete ionization, and simple arguments lead us to expect a mass-luminosity relation with $L \propto M$ (Shu 1982). In practice, modern evolutionary models (e.g., Schaller et al. 1992) yield $L \propto M^2$ for ZAMS stars in the mass range $25 - 120\mathcal{M}_{\odot}$ But, these interior models are characterized by many uncertainties and physical simplifications (Maeder & Conti 1994), and details, such as whether or not convective overshooting is included, matter considerably. It is only now, for example, that the effects of stellar rotation are being included in such models, with significant results (Langer 1998, Maeder & Meynet 2001).

Yet, we rely on these models for interpreting much of the astrophysics related to hot, massive stars, such as the relative number of Wolf-Rayet stars and O-type stars in differing environments (Massey et al. 1995, Massey & Johnson 1998), or the turn-off masses and ages in young clusters (Massey, Waterhouse, & DeGioia-Eastwood 2000). Furthermore, the need for accurate models extends even beyond stellar evolution: the masses that these models predict (as a function of position in the HR diagram) are also the basis for determining the initial mass function and upper mass "cut-offs", which are the fundamental parameters of our understanding of massive-star star formation (see review in Massey 1998).

How good are these stellar evolutionary models? Herrero et al. (1992) noted a significant "mass discrepancy" for masses determined from the evolutionary models compared to those determined using *stellar atmosphere* models. Kudritzki (1990) had described a way that stellar atmospheres could be used to determine stellar masses. First, line fitting yields values for the effective temperature ($T_{\rm eff}$) and surface gravity (g). If the distance and reddening of the star are known, then photometry leads to the star's luminosity, L, since the bolometric correction is also known from the atmosphere models once $T_{\rm eff}$ and g are fixed. Since $L \sim R^2 \times T_{\rm eff}^4$, R can now be determined, and since $g \sim M/R^2$, the star's mass can, in principle, be found (Kudritzki & Hummer 1990; Kudritzki 1991). Even if the star's distance is unknown, the mass can be found if the terminal velocity (v_∞) of the stellar wind can be determined, as v_∞ is linearly proportional to the escape speed [$v_{esc} \sim (M/R)^{1/2}$]: $v_\infty = v_{esc} \times f$, where f is highly insensitive to stellar parameters. Once v_{esc} and g are both known, the mass can be determined from $M \sim v_{esc}^4/g$. Unfortunately, the masses determined in this way appeared to disagree systematically with those determined from stellar evolutionary tracks. Improvements in stellar atmosphere (the inclusion of sphericity, stellar winds, and improved line blanketing) have reduced the "mass discrepancy" (Herrero 2002; Herrero et al. 2002) but not eliminated it. (See also Burkholder, Massey, & Morrell 1998 and Penny, Gies, & Bagnulolo 1999).

However, there is a fundamental and straight-forward way to measure masses directly, by using detached eclipsing, double-lined spectroscopic binaries. Here the simple Newtonian physics yields model-independent values for the masses from only a knowledge of the orbital parameters. However, there are only 12 such systems known that contain O-type stars, and of these only four that contain early O-type stars (Gies 2002). Three of these four are due to our own efforts using Cycle 8 *HST* data (Massey, Penny, & Vukovich 2002). We are proposing here to extend this to five additional potentially very interesting systems, and to obtain critical data on the most massive of these binaries.

2 Enter R136

Candidate high mass binaries were discovered in the R136 cluster by Massey & Hunter (1998). Their Cycle 6 spectroscopic study with the FOS were aimed at determining the initial mass function (IMF) and age of this "super star cluster" in the LMC. Once thought to be a supermassive single object of $2000\mathcal{M}_{\odot}$, we now know that R136 is something even more interesting: the 1-million year old analog of a globular star cluster, with hundreds of early-type stars packed into the central parcsec^3. Massey & Hunter (1998) discovered over 40 stars of spectral type O3, the hottest spectral type, more than the total of all O3 stars known elsewhere. Nevertheless the IMF was found to be Salpeter in slope, matching that of much more modest regions.

In the course of this spectroscopy Massey & Hunter (1998) identified four stars whose spectra contained double absorption lines at the time of observations, demonstrating that these were high-mass binaries. Our followup program in Cycle 8 produced radial velocities, light-curves, and masses for all four system (Massey, Penny, & Vukovich 2002). One of these, R136-038 (O3 V + O6 V) contains the highest mass star ever measured from binary motion, with a mass of $56.9 \pm 0.6\mathcal{M}_{\odot}$ (Fig. 1). Three of these are the earliest eclipsing detached binaries known (Gies 2002); the fourth we found did not eclipse. We found excellent agreement with the masses found from evolutionary models. This suggests that much of the long standing "mass discrepancy" had been in the atmospheric models, although unfortunately our spectra were not of sufficiently high S/N to make a direct comparison by deriving an "atmospheric model" mass for these stars.

We did have one peculiarity, namely that most of the stars in these binaries actually fell slightly to the left of the zero-age main-sequence in the H-R diagram, despite the 1-2 Myr age found from most of the R136 cluster members (Fig. 2). All show synchronous rotation, and have short periods, suggesting that tidal forces may have provided some additional heating of the stellar surfaces. Alternatively, it could simply be that the effective temperatures we adopted (based purely on the spectral types) were too high.

There are two aspects that cry out for further work. First, and foremost, our photometry identified five additional R136 stars which are light variables (Fig. 3), with light-curves which are characteristic of eclipses. Presumably these are also binaries, and spectroscopy (and additional photometry) would allow us to determine spectral types, orbits, orbital inclinations, and masses.

Given their brightness these stars should also prove to be highly massive objects, and we hope will turn out to have slightly longer period and hence remove the possibility that tidal interactions may have affected their locations in the H-R diagram. Secondly, we can obtain sufficiently high S/N on our very high mass system (R136-038) to allow detailed modeling of the photospheric lines in order to determine its “atmospheric model” mass, providing a direct comparison with its orbital measurement of its mass. This would provide an unprecedented test of the new atmosphere models (do the atmosphere models give the right answer for this very high mass star?), while at the same time allowing a better determination of effective temperatures, surface gravities, and bolometric luminosities. We will employ the latest version of the FASTWIND (Santolaya-Rey, Puls & Herrero 1997) code.

We are therefore proposing to obtain spectroscopy on the five newly found light variables, and to better determine the physical properties of R136-38, the highest mass star known. Our simulations, and our successful Cycle 8 experience, suggest that this can be readily accomplished in 15 visits, where we have carefully chosen our timings to assure good phase coverage, as described below. What we will expect this to yield are solid determinations of masses and physical parameters for comparison with stellar models. *HST* is needed due to the extreme crowding of the R136 cluster, which makes ground-based spectroscopy impossible but which is quite achievable with the 0.2 arcsec slit of STIS (see Fig. 2 of Massey & Hunter 1998).

References

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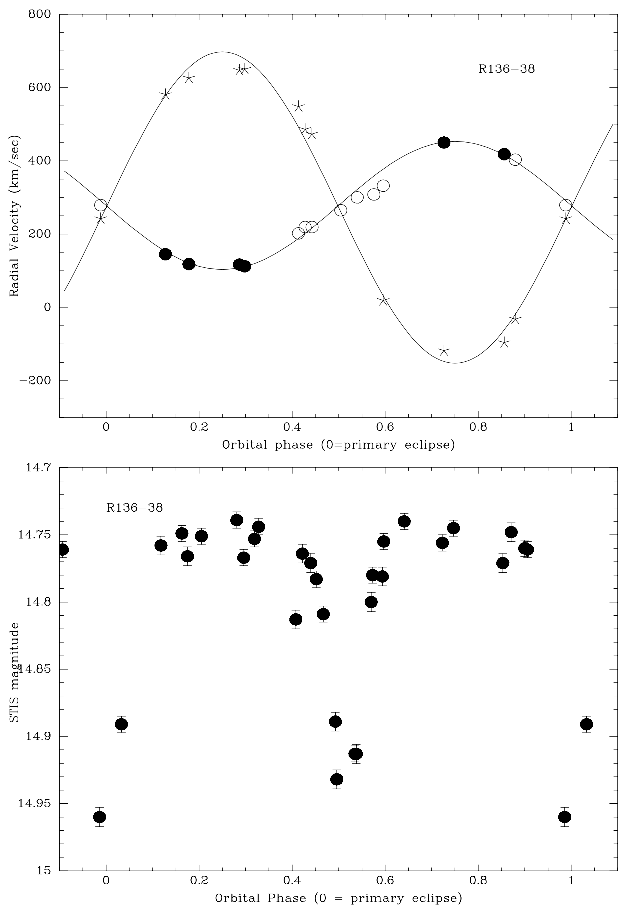

Figure 1: The highest mass binary known consists of an O3 V+O6 V pair, with masses of 57 $\mathcal{M}_\odot$ and 23 $\mathcal{M}_\odot$. Our Cycle 8 observations obtained the radial velocity curve at the top, where solid points show the motion of the primary, and asterisks show the motion of the secondary; the open circles are single-lined phases, not used in the determination of the orbit, but which follow the primary. Below is the light-curve, also obtained with STIS, which sets the orbital inclination to 80.5°. This figure is from Massey, Penny, & Vukovich (2002).

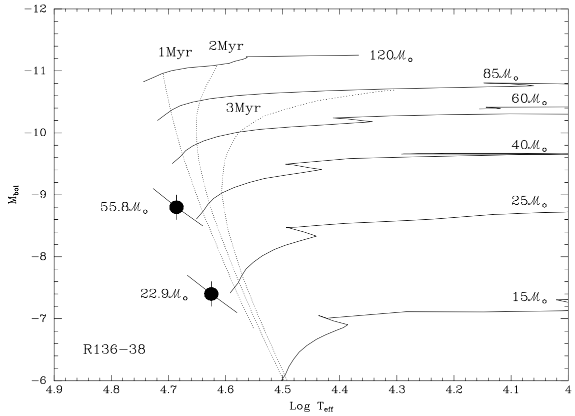

Figure 2: The locations of the R136-038 components in the H-R diagram are shown. Error bars denote the change in location due to a 5% error in the effective temperature scale, and due to uncertainties in the magnitude difference in the two components. The evolutionary tracks (solid lines) are for $z = 0.008$ and come from Schaerer et al. (1993). The dotted lines are isochrones for 1, 2, and 3 Myr, computed from the same models. This figure is from Massey, Penny, & Vukovich (2002).

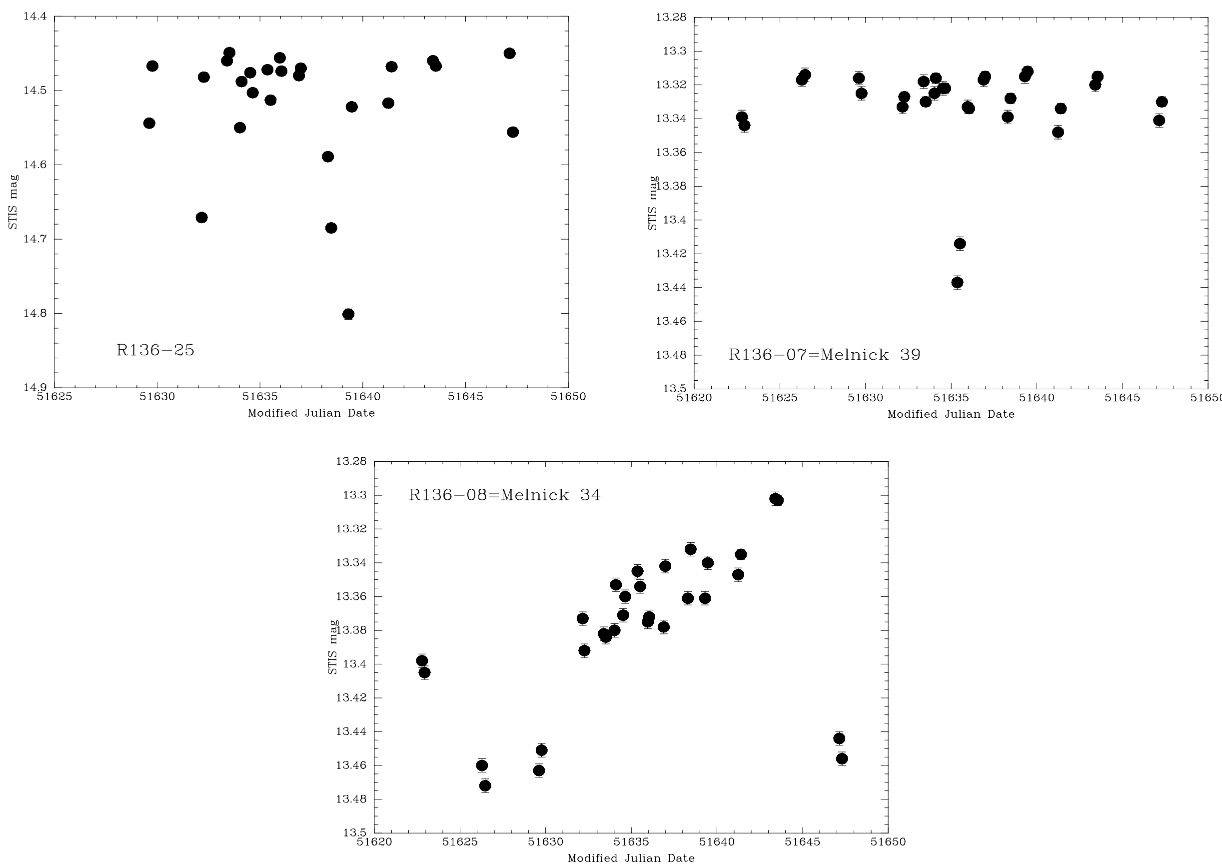

Figure 3: Photometry of our Cycle 8 STIS images revealed 5 new light variables, 3 of which we show here. In R136-25 (upper left) and R136-07 (upper right) we see behavior characteristic of eclipses, with possible periods of 2-3 weeks. R136-08 (Melnick 34) shows a systematic change with a ~ 20 day periodicity; either this is due to orbital motion or something peculiar is happening to this very bright O3 supergiant: interesting no matter which!

Description of the Observations

Star	V	$E(B-V)$	M_V	Spectral Type	Exp. Time (min)*	Rationale
R136-07=Mk39	13.0	0.38	-6.8	O3If*/WN6-A	7	Light variable
R136-08=Mk34	13.3	0.38	-6.5	WNpec	9	Light variable
R136-15=Mk30	13.6	0.38	-6.2	O3If*/WN6-A	11	Light variable
R136-24=R136a7	14.1	0.38	-5.7	O3III(f*)	18	Light variable
R136-25	14.1	0.38	-5.7	O3 V	18	Light variable
R136-38	14.6	0.38	-5.2	O3 V+O6 V	50	Known orbit

* Exposure time computed for a S/N of 75 per spectral resolution element, except for R136-38, where we are aiming for a S/N of 100 for detailed modeling (will include dithering along slit).

We will observe our six targets in the R136 cluster using a similar strategy to what we successfully employed in our Cycle 8 observations (Massey, Penny, Vukovich 2002 ApJ, 565, 982). Although R136 falls in a CVZ during some times of the year, we have not used the CVZ visibility period as we require observations spread over time to obtain good phase coverage; our timing strategy is described below under "Special Requirements".

Each of our 15 visits will require 3 orbits each. We will begin each visit by taking a short pair (1sec+1sec) of STIS images of the entire cluster with the LP filter for photometry. We will then acquire our first spectroscopy target, which is sufficiently well separated from the rest of the cluster to be acquired directly using standard STIS/ACQ; this star will then also serve as our offset for the other five targets. (All of these stars are within an arcminute of each other.) We will then take spectra of all six of the stars listed above, using the G430M grating centered at 4451Å (to include Hγ, He I $\lambda 4471$, and He II $\lambda 4542$), with "small angle maneuvers" (SAMs) to offset from one target to the next. The visit will end with another pair of STIS images of the entire cluster.

1. Guide Star acquisition: 6 minutes
2. STIS image of cluster: (few seconds)
3. STIS overhead for imaging: 5 minutes
4. STIS/ACQ of first star: 6 minutes
5. Spectrum of first star (R136-008): 9 minutes
6. STIS overhead for first spectrum: 6 minutes
7. Small Angle Maneuver (SAM) to second target: 1 minute
8. Spectrum of second star (R136-007): 7 minutes
9. STIS overhead for second spectrum: 1 minute (no change from previous exp).
10. SAM to third target: 1 minute
11. Spectrum of third star (R136-015): 11 minutes
12. STIS overhead for third spectrum: 1 minute (no change from previous exp). End of orbit 1.
13. Earth occultation, followed by 5 minutes for guide star re-acquisition.
14. SAM to fourth target: 1 minute
15. Spectrum of fourth target (R136-038): 50 minutes
16. STIS overhead for fourth target: 1 minute (no change from previous exp). End of orbit 2.
17. Earth occultation, followed by 5 minutes for guide star re-acquisition.

18. SAM to fifth target: 1 minute
19. Spectrum of fifth target (R136-024): 18 minutes
20. STIS overhead for fifth target: 1 minute (no change from previous exp).
21. SAM to sixth, and final, target: 1 minute
22. Spectrum of sixth target (R136-025): 18 minutes
23. STIS overhead for sixth target: 1 minute (no change from previous exp).
24. SAM back to cluster center: 1 minute
25. STIS image of cluster: (few seconds)
26. STIS overhead for imaging: 5 minutes. End of visit.

For our photospheric analysis of R136-38, we will take full-orbit exposures in the blue for 8 of the visits, and will co-add the double-line phases using stellar tomographic techniques (Penny et al. 1999). For the other 7 will will instead obtain Hα (G750M grating) data to obtain the mass-loss rates, needed for the analysis as shown by our preliminary modeling work on the existing spectra.

Special Requirements

Timing is critical not only in comedy (Penn & Teller 1997, *How to Play in Traffic*, p. 103), but also in determining orbit solutions when the periods are not know a priori. We plan to use the same procedure as we did in our successful Cycle 8 propose, and separate our visits by intervals determined by a geometrical series. This scheme was originally developed by Abi Saha for observing cepheids as part of the distance scale key project. As in Cycle 8, we'll ask for intervals of 0.5×1.175^n (days), where n=1,14 (Massey, Penny, Vukovich 2002, ApJ, 565, 982). Simulations show this provides uniformly good phase coverage for periods from 1 to 30 days (Fig. 4. The longest gap between successive visits will be 3.7 days and the shortest 0.5 days, and will span an observing "season" of 24 days. We will put our shortest intervals in the middle and the longer intervals towards either end for optimal performance. Scheduling this proved straight-forward in Cycle 8, as some slop (0.2 days) between when we would like to be scheduled, and when we can actually be scheduled, makes little difference, as shown below.

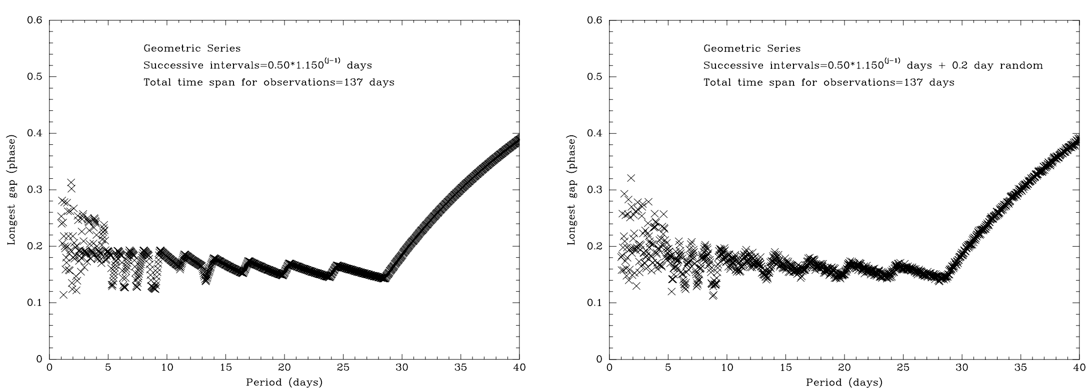

Figure 4: Our simulations demonstrate that we obtain good phase coverage for all periods from 1 to 30 days when we time the intervals using our geometrical series. The plot on the right shows that a random slop of 0.2 days in our scheduling makes little difference on the resulting phase coverage.

Coordinated Observations

Justify Duplications

Repeated observations are needed to establish orbits and light-curves.

Previous Related HST Programs

The following two programs are the direct predeecessors to the current proposal:

- **"Star Formation in the Prototype Super Star Cluster R136":** GO-6417 (Cycle 6, PI Massey). This was the first study to obtain spectra of a significant number of stars in the R136 cluster in the LMC, demonstrating that the IMF was Salpeter, and that whatever the mass is of the highest mass star, we have yet to encounter it in nature. Publications included:
  - Massey & Hunter 1998, "Star Formation in R136: A Cluster of O3 Stars Revealed by Hubble Space Telescope Spectroscopy", ApJ, 493, 180
  - Massey & Hunter 1998, "R136: A Cluster of O3 Stars" (invited talk), in Boulder-Munich II: Properties of Hot, Luminous Stars, ed. Howarth (ASP), 355
  - Massey 1998 "The Initial Mass Function of Massive Stars in the Local Group" (invited review), in The Stellar Initial Mass Function, 38th Herstmonceux Conf., ed. Gilmore & Howell (ASP), 17
  - Hunter 1999 "The Stellar Population of R136" (invited talk), in New Views of the Magellanic Clouds, IAU Symp. 190, ed. Suntzeff, Hesser, & Bohlender (ASP), p. 217
  - Walborn et al. 2002 "A New Spectral Classification System for the Earliest O Stars: Definition of Type O2", AJ, 123, 2754
  - The resulting papers generated a great deal of public interest: Our work was featured on the Univ. of Texas' STARDATE radio program broadcast March 13, 1998, was included in Astronomy Magazine's June 1998 "Astronews", and appears in the January 1998 Sky and Telescope ("Hubble Spies Supermassive Stars")
- **"Tests of Stellar Models Using Four Extremely Massive Spectroscopic Binaries in the R136 Cluster":** GO-8217 (Cycle 8, PI Massey). We had previously (GO-6417) discovered four extremely early-type stars in the R136 cluster that showed double absorption lines, suggesting that they were spectroscopic binaries. In this program I went after them with STIS/CCD in order to obtain radial velocities and light-curves to produce orbits and Keplerian masses to compare these to evolutionary models. We discovered the highest mass binary yet known (57 $\mathcal{M}_\odot$), and established excellent agreement with the evolutionary models. We also discovered five new light-variables in this cluster, which form the basis for the current proposal. The study was published in:

- Massey, Penny, & Vukovich 2002, "Orbits of Four Very Massive Binaries in the R136 Cluster", ApJ, 565, 982
- In addition, a press release invited by the AAS for the Jan 2001 meeting resulted in a very nice popular article in the the June 2002 Sky and Telescope (News Notes).

The following is a complete list (in addition to the above) of the *HST* programs for which Massey has been the PI or a CoI:

- **"Stellar Winds in M31, M33 and NGC6822":** GO-1150 (Cycle 1, Hutchings PI), GO-2581 (Cycle 1, Bianchi PI), GO-3954 (Cycle 2, Hutchings, PI), GO-5179 (Cycle 4, Hutchings, PI), GO-5494 (cycle 5, Bianchi, PI), GO-6567 (cycle 6, Bianchi, PI). These were are early attempts to use *HST* (both with GHRS and FOS) to obtain UV spectra of hot stars in M31 and M33 (and subsequently NGC 6822). The data and analysis were published in the following papers (excluding meeting abstracts):
  - Hutchings, Bianchi, Lamers, Massey, & Morris 1992 ,"Hubble Space Telescope Spectroscopy of OB Stars in M31", ApJ, 400, 35
  - Bianchi, Lamers, Hutchings, Massey, Kudritzki, Herrero, & Lennon 1994, "Ultraviolet and Optical Spectroscopy of a B Supergiant Star in M31", A&A, 292, 213
  - Haser, Lennon, Kudritzki, Puls, Pauldrach, Bianchi, & Hutchings 1995, "The Stellar Wind of an O8.5 I(f) Star in M31", A&A, 295, 136
  - Bianchi, Hutchings, & Massey 1996, "The Winds of Hot Stars in External Galaxies. III. UV Spectroscopy of O and B Supergiants in M31 and M33", AJ, 111, 2303
  - Bianchi, Clayton, Bohlin, Hutchings, Massey 1996, "Ultraviolet Extinction by Interstellar Dust in External Galaxies: M31", ApJ, 471, 203
  - Bianchi, Scuderi, Massey, & Romaniello 2001, "The Massive Star Content of NGC 6822: Ground-Based and Hubble Space Telescope Photometry", AJ, 121, 2020
- **"The Evolution of Massive Stars: Closing the Loop Observationally...":** GO-5998 (Cycle 5, PI Massey), GO-7464 (Cycle 7, PI Massey). These two projects were intended to complement on-going ground-based studies of coeval regions in M31 and M33. In GO-5998 I obtained WFPC2 images of selected OB associations in these two galaxies in order to see establish whether particular high luminosity stars were single or simply blends undetected from the ground; the data were then used to improve the ground-based photometry. These data were then used to select stars for further spectroscopic observations, with the MMT and KPNO 4-m telescopes. A STIS/CCD proposal was then awarded time (GO-7464) in order to obtain spectra of the stars that had proven too difficult (crowded) to do from the crowd. The ground-based spectroscopic part of the program was delayed while the MMT underwent its conversion to 6.5-m, and the subsequent commissioning pains. Now that the telescope is functional I hope to have the total project completed next year. The data have been partially published in:

- Massey, Bianchi, Hutchings, & Stecher 1996, "The UV-brightest Stars of M33 and Its Nucleus: Discovery, Photometry, and Optical Spectroscopy", ApJ, 469, 629
- Massey, Armandroff, Pyke, Patel, & Wilson 1995, "Hot Luminous Stars in Selected Regions of NGC 6822, M31, and M33", AJ, 110, 2715
- Massey 1998, "Observations of the Most Luminous Stars in Local Group Galaxies", in Stellar Astrophysics for the Local Group, ed. A. Aparicio, A. Herrero, and F. Sanchez (invited series of lectures), 95

- **"The Physical Parameters of the Hottest, Most Luminous Stars":** GO-7739 (GO-6417 "carryover" time in Cycle 7, PI Massey), GO-8633 (Cycle 9 snap, PI Massey), and GO-9412 (Cycle 11, PI Massey). We are using STIS/FUV-MAMA data to obtain data on stellar winds in the hottest and most massive stars in the Magellanic Clouds, combining this with high S/N, high resolution optical data obtained at CTIO. Our "snap" program in Cycle 9 had a very poor completion rate, and so the Cycle 11 TAC kindly assigned us sufficient time to complete the project. The data are still being taken. The "carryover" Cycle 7 time (from our Cycle 6 R136 program) obtained high S/N optical data on R136 stars, which are being combined with this for a single paper. Once the data-taking is complete this Spring, we will get to work on the paper. The analysis is complete for the stars for which data have been obtained.
- **"The Mass-Luminosity Relationship for High Mass Stars":** GO-9097 (Cycle 10, PI Massey). We exampled about a dozen "nearby" O-type stars (out to 2 kpc) with the FGS looking for previously unresolved binaries that would be suitable for long-term monitoring with HST/FGS to determine orbits. We've found several, and our results are being prepared for publication (with Otto Franz and Larry Wassermann).